

CLAIMS

What is claimed is:

1. A lithium-sulfur battery comprising:  
a positive electrode having an electron-conductive path and an ion-conductive path and comprising:  
a positive active material including an active sulfur, and  
pores of an average size of up to 20  $\mu\text{m}$  having both electron-conductive and ion-conductive properties, where the active sulfur is disposed in the pores during an electrochemical reaction of the lithium-sulfur battery;  
a negative electrode comprising a negative active material selected from the group consisting of a lithium metal, a lithium-containing alloy, materials which can reversibly intercalate/deintercalate lithium ions, or materials which can reversibly form a chemical compound with lithium;  
a separator interposed between said positive and negative electrodes; and  
an ion-conductive electrolyte.
2. The lithium-sulfur battery according to claim 1, wherein the average size of the pores is up to 10  $\mu\text{m}$ .
3. The lithium-sulfur battery according to claim 1, wherein the average size of the pores is up to 5  $\mu\text{m}$ .
4. The lithium-sulfur battery according to claim 1, wherein said positive electrode is prepared by a method comprising:  
mixing an elemental sulfur ( $\text{S}_8$ ) powder, a conductive agent, and a binder to provide a positive active material slurry; and  
coating the positive active material slurry on a current collector.
5. The lithium-sulfur battery according to claim 4, wherein an average particle size of the elemental sulfur is up to 20  $\mu\text{m}$ .

6. The lithium-sulfur battery according to claim 4, wherein an average particle size of the elemental sulfur is up to 10  $\mu\text{m}$ .
7. The lithium-sulfur battery according to claim 4, wherein an average particle size of the elemental sulfur is up to 5  $\mu\text{m}$ .
8. The lithium-sulfur battery according to claim 4, wherein the mixing step is performed with a ball mill.
9. The lithium-sulfur battery according to claim 4, wherein, after preparing said positive electrode, a polysulfide solution is added to the lithium-sulfur battery.
10. The lithium-sulfur battery according to claim 9, wherein the positive electrode is prepared by:
  - coating a composition including the conductive agent, the binder, and a plasticizer on the current collector;
  - removing the plasticizer from the current collector with an organic solvent to generate ones of the pores on the current collector; and
  - injecting the polysulfide solution into the generated ones of the pores.
11. The lithium-sulfur battery according to claim 10, wherein the composition further comprises elemental sulfur ( $\text{S}_8$ ).
12. The lithium-sulfur battery according to claim 10, wherein an amount of the plasticizer is 5 to 80% by weight of said positive electrode.
13. The lithium-sulfur battery according to claim 10, wherein the plasticizer is at least one selected from the group consisting of dibutyl phthalate, dimethyl phthalate, diethyl phthalate, trishutoxyethyl phosphate, propylene carbonate, ethylene carbonate, trimethyl trimellitata, and a mixture thereof.
14. The lithium-sulfur battery according to claim 10, wherein the organic solvent is selected from the group consisting of ether, diethyl ether, hexane, petroleum ether, ligroin,

cyclohexane, methanol, ethanol, dichloromethane, trichloroethylene, and trichloroethane, and a mixture thereof.

15. The lithium-sulfur battery according to claim 10, wherein the binder is selected from the group consisting of poly(vinyl acetate), polyvinyl alcohol, polyethylene oxide, polyvinyl pyrrolidone, alkylated polyethylene oxide, cross linked polyethylene oxide, polyvinyl ether, poly(methyl methacrylate), polyvinylidene fluoride, copolymer of polyhexafluoropropylene and polyvinylidene fluoride, poly(ethyl acrylate), polytetrafluoro ethylene, polyvinyl chloride, polyacrylonitrile, polyvinylpyridine, polystyrene, poly(butylal-co-vinyl alcohol-co-vinyl acetate), poly(methyl metacrylate-co-ethyl acrylate), poly vinyl chloride co-vinyl acetate, polyalkylene oxide, poly(1-vinylpyrrolodone-co -vinyl acetate) and cellulose acetate, and a mixture thereof.

16. The lithium-sulfur battery according to claim 10, wherein the current collector is rolled prior to removing the plasticizer.

17. The lithium-sulfur battery according to claim 1, wherein the ion-conductive properties are supplied using an ionic conductive medium selected from the group consisting of ethylene carbonate, propylene carbonate, dioxolane, sulfolane, xylene, diglyme, tetrahydro furan, tetraglyme, sulfone, dimethyl sulfone, dialkyl carbonate, butyrolactone, N-methyl pyrrolidone, tetramethyl urea, glyme, crown ether, dimethoxy ethane, N,N-diethyl formamide, N,N-diethyl acetamide, hexamethyl phosphoamide, pyridine, dimethyl sulfoxide, N,N-dimethyl acetamide, tributyl phosphate, trimethyl phosphate, N,N,N,N-tetraethyl sulfamide, tetramethylene diamine, tetramethyl propylene diamine, pentamethylene triamine, methanol, ethylene glycol, polyethylene glycol, nitromethane, trifluoro acetic acid, trifluoro methane sulfonic acid, sulfur dioxide, and boron trifluoride, and a mixture thereof.

18. A method of preparing a positive electrode for use in a lithium-sulfur battery, the method comprising:

mixing an elemental sulfur ( $S_8$ ) powder, a conductive agent, and a binder to provide a positive active material slurry; and

coating the positive active material slurry on a current collector,

wherein, during an electrochemical reaction, an active sulfur from the elemental sulfur powder is disposed in pores on the current collector, and the pores have an average size of up to 20  $\mu\text{m}$  and are both electron-conductive and ion-conductive.

19. The method according to claim 18, wherein the average particle size of the elemental sulfur is up to 20  $\mu\text{m}$ .

20. The method according to claim 18, wherein the average particle size of the elemental sulfur is up to 10  $\mu\text{m}$ .

21. The method according to claim 18, wherein the average particle size of the elemental sulfur is up to 5  $\mu\text{m}$ .

22. The method according to claim 18, wherein said mixing further comprises grinding the elemental sulfur powder with a ball mill to control a particle size of the elemental sulfur powder.

23. The method according to claim 18, further comprising:  
coating a plasticizer on the current collector; and  
removing the plasticizer from the current collector with an organic solvent to generate ones of the pores on the current collector.

24. The method according to claim 23, wherein an amount of the plasticizer is 5 to 80% by weight of the positive electrode.

25. The method according to claim 23, wherein the plasticizer is at least one selected from the group consisting of dibutyl phthalate, dimethyl phthalate, diethyl phthalate, trishutoxyethyl phosphate, propylene carbonate, ethylene carbonate, trimethyl trimellitata, and a mixture thereof.

26. The method according to claim 23, wherein the organic solvent is selected from the group consisting of ether, diethyl ether, hexane, petroleum ether, ligroin, cyclohexane, methanol, ethanol, dichloromethane, trichloroethylene, and trichloroethane, and a mixture thereof.

27. The method according to claim 23, wherein the binder is selected from the group consisting of poly(vinyl acetate), polyvinyl alcohol, polyethylene oxide, polyvinyl

pyrrolidone, alkylated polyethylene oxide, cross linked polyethylene oxide, polyvinyl ether, poly(methyl methacrylate), polyvinylidene fluoride, copolymer of polyhexafluoropropylene and polyvinylidene fluoride, poly(ethyl acrylate), polytetrafluoro ethylene, polyvinyl chloride, polyacrylonitrile, polyvinylpyridine, polystyrene, poly(butyracal-co-vinyl alcohol-co-vinyl acetate), poly(methyl metacrylate-co- ethyl acrylate), poly vinyl chloride co-vinyl acetate, polyalkylene oxide, poly(1-vinylpyrrolodone-co -vinyl acetate) and cellulose acetate, and a mixture thereof.

28. The method according to claim 23, further comprising rolling the coated current collector prior to said removing the plasticizer.

29. A positive electrode for use in a lithium-sulfur battery, comprising:  
a positive active material including an active sulfur; and  
a current collector coated with the positive active material and, during an electrochemical reaction of the lithium-sulfur battery, has pores of an average size of up to 20  $\mu\text{m}$  in which the active sulfur is disposed and having both electron-conductive and ion-conductive properties,  
wherein the positive electrode has an electron-conductive path and an ion-conductive path.

30. The positive electrode according to claim 29, wherein the average size of the pores is up to 10  $\mu\text{m}$ .

31. The positive electrode according to claim 29, wherein the average size of the pores is up to 5  $\mu\text{m}$ .

32. The positive electrode according to claim 29, wherein said positive active material comprises an elemental sulfur ( $\text{S}_8$ ) powder, a conductive agent, and a binder coated on said current collector.

33. The positive electrode according to claim 32, wherein an average particle size of the elemental sulfur is up to 20  $\mu\text{m}$ .

34. The positive electrode according to claim 32, wherein an average particle size of the elemental sulfur is up to 10  $\mu\text{m}$ .

35. The positive electrode according to claim 32, wherein an average particle size of the elemental sulfur is up to 5  $\mu\text{m}$ .

36. The positive electrode according to claim 32, wherein the binder is selected from the group consisting of poly(vinyl acetate), polyvinyl alcohol, polyethylene oxide, polyvinyl pyrrolidone, alkylated polyethylene oxide, cross linked polyethylene oxide, polyvinyl ether, poly(methyl methacrylate), polyvinylidene fluoride, copolymer of polyhexafluoropropylene and polyvinylidene fluoride, poly(ethyl acrylate), polytetrafluoro ethylene, polyvinyl chloride, polyacrylonitrile, polyvinylpyridine, polystyrene, poly(butylal-co-vinyl alcohol-co-vinyl acetate), poly(methyl metacrylate-co- ethyl acrylate), poly vinyl chloride co-vinyl acetate, polyalkylene oxide, poly(1-vinylpyrrolodone-co -vinyl acetate) and cellulose acetate, and a mixture thereof.

37. The positive electrode according to claim 29, wherein the ionic conductive properties are supplied by an ionic conductive medium selected from the group consisting of ethylene carbonate, propylene carbonate, dioxolane, sulfolane, xylene, diglyme, tetrahydro furan, tetraglyme, sulfone, dimethyl sulfone, dialkyl carbonate, butyrolactone, N-methyl pyrrolidone, tetramethyl urea, glyme, crown ether, dimethoxy ethane, N,N-diethyl formamide, N,N-diethyl acetamide, hexamethyl phosphoamide, pyridine, dimethyl sulfoxide, N,N-dimethyl acetamide, tributyl phosphate, trimethyl phosphate, N,N,N,N-tetraethyl sulfamide, tetramethylene diamine, tetramethyl propylene diamine, pentamethylene triamine, methanol, ethylene glycol, polyethylene glycol, nitromethane, trifluoro acetic acid, trifluoro methane sulfonic acid, sulfur dioxide, and boron trifluoride, and a mixture thereof.

38. The lithium-sulfur battery of claim 1, wherein said electrolyte is a solid.

39. The lithium sulfur battery of claim 38, wherein said solid electrolyte comprises one of a glass electrolyte, a polymer electrolyte, a ceramic electrolyte, and a mixture of polymer electrolyte with a suitable supporting electrolyte salt.